The Coal-Seq Project: Key Results from Field, Laboratory, and Modeling Studies

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Abstract

In October 2000, a multi-year government-industry R&D collaboration known as the Coal-Seq project was launched in the United States. Participants in the project include the U.S. Department of Energy as the project sponsor, Advanced Resources International, Burlington Resources, and BP America. The project objectives are to evaluate the feasibility of CO₂ sequestration in deep, unmineable coalseams using enhanced coalbed methane (ECBM) recovery technology. The Coal-Seq project is achieving its objectives via reservoir simulation studies of existing ECBM pilot projects in the San Juan basin, laboratory modeling studies of coal behavior, technical and economic sensitivity studies, and assessments of the potential and economic performance for ECBM recovery and CO₂ sequestration in deep, unmineable coals.

Since its inception, and now in its final year, many important findings have emerged from the project, some of the more notable being:

- CO₂ injection into coal can significantly improve methane recovery. At the Allison Unit CO₂-ECBM pilot in the San Juan basin, methane recovery was improved from 77% to 95% of original gas in place within the central pilot area.

- Coal permeability and CO₂ injectivity was substantially reduced with CO₂ injection (by up to an order of magnitude near the wells, and extending to an estimated 1,000 ft from the wellbores). This has a detrimental effect to ECBM/sequestration economics.

- While existing reservoir simulation models yield essentially similar results, the theoretical models they are based upon for multi-component sorption, diffusion and phase behavior may not accurately replicate actual reservoir behavior. Specifically, coal swelling cannot be adequately modeled in a dynamic fashion.

- N₂-ECBM appears more economically favorable than CO₂-ECBM. However, from a carbon sequestration perspective, a gas comprising of mostly CO₂ appears the most favorable.

- A technical/economic sensitivity has shed light on the most favorable coal conditions for sequestration. These include deep, high-rank coals with low permeability and that have not been previously developed for conventional coalbed methane production. However, this assumes technology is developed to overcome reduced injectivity due to matrix swelling.

- An assessment of CO₂-ECBM/sequestration potential in the U.S. suggests a potential resource of 150 Tcf of gas and a sequestration capacity of 90 Gt of CO₂ exists.
Introduction

In October 2000, a multi-year government-industry R&D collaboration known as the Coal-Seq project was launched in the United States. Participants in the project include the U.S. Department of Energy (DOE) as the project sponsor, Advanced Resources International (ARI), Burlington Resources, and BP America. The project objectives are to evaluate the feasibility of CO₂ sequestration in deep, unmineable coalseams using enhanced coalbed methane (ECBM) recovery technology. The Coal-Seq project is achieving its objectives via reservoir simulation studies of existing ECBM pilot projects in the San Juan basin, laboratory/modeling studies of coal behavior, technical and economic sensitivity studies, and assessments of the potential and economic performance for ECBM recovery and CO₂ sequestration in deep, unmineable coals. This paper presents the work performed and key findings from this important R&D project.

Project Activities and Major Findings

Allison Unit CO₂-ECBM Pilot

The Allison Unit CO₂ ECBM pilot in the San Juan Basin, operated by Burlington Resources, is the largest and longest running project of its kind, with four injector wells, 16 producers, and 6-years of injection history during which 370,000 tons of CO₂ was injected. A detailed reservoir study of the pilot, which included performing a full-field characterization, simulation history-matching, and performance forecasting, indicated that CO₂ injection improved methane recovery in the affected area from 77% to 95% of the original gas in place (Figure 1). An economic analysis of the pilot indicated that it would have provided a positive net present value at gas prices above $2.60/Mcf, not including the impact of Section 29 tax credits. Thus the outlook for value-adding carbon sequestration in coal is promising with today’s energy prices.

Coal Permeability Reduction with CO₂ Injection

During CO₂ injection at the Allison Unit, a reduction in injectivity of about 60% was initially observed (Figure 2). This was the first documented field evidence confirming the phenomena of coal swelling and permeability reduction with CO₂ injection, as long predicted by industry experts. Studies of this behavior, including well testing, indicated that the coal permeability near the well was reduced by up to two orders-of-magnitude, but that the effects gradually became less severe further from the well, and affected the coal a maximum distance of about 1,000 feet from the well. This profile of permeability decline is consistent with a 60% reduction in injectivity. What was unexpected was the rebound in injectivity following the initial decline. Further analysis concluded that this was caused by a continued decrease in overall reservoir pressure with time (methane production volumes from the reservoir were considerably greater than CO₂ injection volumes into it), which enabled the adsorbed CO₂ near the well to desorb and migrate further into the reservoir, causing matrix shrinkage and a permeability increase, similar to that observed during primary methane depletion. An assessment of the performance of the pilot had injection rates been much higher (i.e., no reduced permeability or an effective strategy to mitigate it) was performed and suggested a significant improvement in economics would have resulted. Thus finding a solution to this problem should be a priority R&D topic for the future.
**Modeling Reservoir Mechanics**

Through the course of simulating the results of the Allison Unit and another, N₂-ECBM pilot in the San Juan Basin (the Tiffany Unit, operated by BP America)³, it was discovered that certain injection and production pressure behavior related to matrix shrinkage/swelling could not be satisfactorily replicated. Benchmarking of the simulator used for the study, ARI’s COMET³, against other industry simulators on standardized sequestration/ECBM problems, as well as running the Allison/Tiffany models using another simulator, resulted in essentially similar results, and suggests a fundamental disconnect exists between the physics used in the simulators and actual reservoir behavior. Further study indicated that the theories used in the simulators are not accurate for modeling multi-component sorption, bi-directional diffusion, and CH₄-CO₂-N₂ gas properties. These findings are based upon actual laboratory studies. Upgrading this capability should be a priority research topic for carbon sequestration in coals, for the lack of reliable predictive models will present a considerable barrier to technology adoption.

**Benefits of Nitrogen**

Based on the results of the Tiffany Unit N₂-ECBM reservoir modeling study, the potential benefits of retaining some N₂ in a flue gas stream for sequestration purposes were indicated – N₂ is a very effective ECBM injectant, providing a much more rapid ECBM response than CO₂. While the breakeven gas price for Tiffany was slightly less than that for Allison (~$2.40/Mcf), not including the benefits of Section 29 tax credits, the upside with today’s gas prices was much greater. Thus one can easily envision how the inclusion of some N₂ in a flue gas stream for sequestration would improve overall sequestration economics.

**Sensitivity Study**

To examine the impact of flue gas composition, as well as other reservoir and operating parameter, on technical and economic performance of ECBM/sequestration projects, a screening model was developed⁴. A sensitivity study was then performed using it to evaluate the impact of various parameters on project performance⁵. That study indicated that deeper, higher rank and lower permeability coals, that have not been previously developed for conventional coalbed methane production previously (i.e., a large gas resource can be recovered to offset sequestration costs), are the best economic environments for CO₂ sequestration. However, this assumes that technology is developed to overcome or otherwise mitigate the detrimental effects of coal swelling and injectivity reduction. It was also noted that in most cases, near-pure CO₂ provides the best economic results. This is due to additional capital costs related to N₂ separation and recycling, and lesser net sequestration volumes (due to lesser CO₂ injection volumes as well as additional carbon emissions associated with nitrogen generation and handling). However, in the lowest permeability and highest rank coal environments, the inclusion of more N₂ appears very promising.
CO₂-Sequestration/Capacity Assessment

A national assessment of the U.S. sequestration capacity in coals, as well as associated incremental ECBM recovery was performed. That assessment, which evaluated 17 basins/regions in the U.S., estimated that the CO₂ sequestration capacity is about 90 Gt. Between 25 and 30 Gt of CO₂ can be sequestered at a profit, and 80 – 85 Gt can be sequestered at costs of less than $5/ton. The ECBM recovery potential associated with this sequestration is estimated to be over 150 Tcf. Several Rocky Mountain basins, including the San Juan, Raton, Powder River and Uinta appear to hold the most favorable conditions for sequestration economics. The Gulf Coast and the Central Appalachian basin also appear to hold promise as economic sequestration targets, depending upon gas prices. In general, and similar to the results of the sensitivity study, the “greenfield” areas (those areas that are not expected to produce primary coalbed methane commercially) appear more favorable for sequestration economics than the “brownfield” areas. This is because there is more in-place methane to recover in these settings.

Conclusions

Some of the main conclusions drawn from the project to-date include:

- CO₂ injection into coal can significantly improve methane recovery. At the Allison Unit CO₂-ECBM pilot in the San Juan basin, methane recovery was improved from 77% to 95% of original gas in place within the central pilot area.

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References


Figure 1: Coal Methane Content Following CO₂ Injection, Allison Unit

Figure 2: Injectivity Decline in a CO₂ Injector Well, Allison Unit